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VISUAL EVOKED POTENTIAL AUGMENTING-REDUCING AND PERSONALITY: THE VERTEX AUGMENTER IS A SENSATION SEEKER

Jeffrey H. Lukas

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Assessment of personality correlates of evoked potential augmenting-reducing (A/R) requires appropriate psychophysiological procedures to assure valid assessment of cortical functioning (Tepas, Guiteras and Klingaman, 1974). Using a Maxwellian-view optical system to precisely control retinal illuminance, two studies compared A/R at O_z and C_z and their correlation with personality measures: Zuckerman's Sensation Seeking Scale and Vando's Reducer-Augmenter Scale. Both the amplitude and latency of the occipital potentials varied in a very systematic and consistent manner with intensity and the A/R measures failed to correlate with personality. In contrast, the vertex potentials, which are known to be affected by nonsensory factors such as cortical arousal and attention, were significantly correlated with personality. The vertex augmenter is a sensation seeker and, as previously found with animals (Lukas and Siegel, 1977a), this relationship was true only for the A/R slopes to the more intense light flashes. Apparently, how the brain responds to intense sensory stimulation as measured by A/R determines how people respond behaviorally to intense sensations.

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VISUAL EVOKED POTENTIAL AUGMENTING–REDUCING AND PERSONALITY: THE VERTEX AUGMENTER IS A SENSATION SEEKER*

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(*Received 30 May 1986*)

Summary—Assessment of personality correlates of evoked potential augmenting–reducing (A/R) requires appropriate psychophysiological procedures to assure valid assessment of cortical functiong (Tepas, Guiteras and Klingaman, 1974). Using a Maxwellian-view optical system to precisely control retinal illuminance, two studies compared A/R at O_z and C_z and their correlation with personality measures: Zuckerman's Sensation Seeking Scale and Vando's Reducer–Augmenter Scale. Both the amplitude and latency of the occipital potentials varied in a very systematic and consistent manner with intensity and the A/R measures failed to correlate with personality. In contrast, the vertex potentials, which are known to be affected by nonsensory factors such as cortical arousal and attention, were significantly correlated with personality. The vertex augmenter is a sensation seeker and, as previously found with animals (Lukas and Siegel, 1977a), this relationship was true only for the A/R slopes to the more intense light flashes. Apparently, how the brain responds to intense sensory stimulation as measured by A/R determines how people respond behaviorally to intense sensations.

INTRODUCTION

Buchsbaum and Silverman (1968) developed an electrophysiological procedure using visual evoked potentials (VEPs) to measure individual differences in response to sensory stimulation referred to as augmenting–reducing (A/R). When light intensity is varied from dim to bright, the VEP amplitude may increase at different rates or even decrease in some subjects. Augmenters have positive VEP amplitude slopes while reducers have less positive or even negative slopes to the same series of flash intensities (Buchsbaum and Pfefferbaum, 1971; Silverman, Buchsbaum and Henkin, 1969). Subsequently, many studies have reported behavioral and personality correlates of A/R in both normal and clinical populations (e.g. Barnes, 1976; Zuckerman, Buchsbaum and Murphy, 1980). In particular, Zuckerman (1984) has reviewed human and animal data supporting the biological basis for the sensation-seeking trait and its relationship with A/R. However, in order to develop a personality theory based on individual differences in central nervous system functioning, it is essential that the VEP slope reflects underlying neural mechanisms. In a critique of the A/R paradigm, Tepas, Guiteras and Klingman (1974) described four sources of variance that could easily distort a true positive and linear VEP amplitude slope: (1) artefacts produced by inadequate stimulus control or equipment produced signals; (2) inappropriate or inadequate detection and measurement of the VEP; (3) EEG variability; or (4) VEP variability. Using optimal stimulus, recording, and VEP component identification and measurement procedures, they reported that linear regression analyses of their amplitude and latency data accounted for over 92% of the variance. Without appropriate stimulus control, results "may merely reflect a change in sensory stimulation due to unintended interaction of experiment conditions with poor stimulus control and, therefore, do not provide us with any valid information concerning neural mechanisms" (p. 536).

It is well documented that in a free viewing situation the VEP amplitude increases as flash intensity increases up to a point, then saturates or declines with further increases in intensity (e.g.

*Preliminary results from the first study were presented at the annual meeting of the Society for Neuroscience, Los Angeles, October 1981. The second study was presented at the Society for Psychophysiological Research annual meeting, Washington, D.C. October 1982. This paper may be reproduced in full or in part for any purpose of the United States Government.

Regan, 1972; Vaughan, 1966). In a free viewing situation, subjects differ in their ability to maintain fixation or tolerate bright flashes, which may distort the true slope without it being apparent to either subject or experimenter. Idiosyncratic trends in VEP amplitude slope also occur when light flashes are provided by a Maxwellian-view optical system, which precisely controls retinal illuminance (e.g. Armington, 1964, 1968; DeVoe, Ripps and Vaughan, 1968; Shipley, Jones and Fry, 1966; Tepas and Armington, 1962; Wicke, Donchin and Lindsley, 1964). Although these studies were not concerned with A/R or personality issues, they clearly demonstrated that VEP slope differences existed among subjects even under the most stringent control procedures. Therefore, the possibility exists that slope differences may depend on CNS excitability and cortical functioning and therefore relate to personality.

The study of brain–behavior relationships requires a solid methodological foundation to insure that VEP variability reflects differences in neuronal processing. Buchsbaum has argued, based on experimental and theoretical grounds, that augmenting–reducing is a vertex phenomenon (Buchsbaum, 1976; Buchsbaum and Pfefferbaum, 1971), yet others have reported VEP A/R at the occiput (e.g. Birchall and Claridge, 1979; Claridge, Robinson and Birchall, 1985). Tepas *et al.* based their criticism of A/R on measurement of the N_{70}–P_{95} component of bipolar O_z–C_z recordings. However, Kress (1975, 1976), compared the O_z N_{70}–P_{95} component with the C_z N_1–P_2 component, and concluded that the C_z component for most subjects was not linearly related to intensity and was more likely related to factors such as EEG activation and attention. The present study examined the first major O_z component (N_{70}–P_{95}) measured by Tepas and Kress with the C_z P_1–N_1 component usually associated with VEP A/R. The stimulus and recording procedures were patterned after those reported by Tepas such that subjects' attention and fixation point were controlled, pupillary responses eliminated as a source of variability and retinal illuminance controlled across a broad range of intensities. The rationale was that a positive, linear occipital slope would serve as a measure of stimulus control, in order to insure that augmenting–reducing vertex slopes would indicate true differences in cortical functioning.

Two experiments are reported: the first deals exclusively with VEP slopes recorded simultaneously from C_z and O_z. The second study examined the personality correlates of A/R recorded at O_z and C_z. The primary emphasis was on sensation seeking, which has been reported to be correlated with C_z A/R (Zuckerman, 1984; Zuckerman, Murtaugh and Siegel, 1974). The question was whether the vertex augmenter would be a sensation seeker even when VEPs were collected under rigorous stimulus and recording procedures.

Subjects. Ten volunteer subjects, eight males and two females, were paid to participate in this study. Subjects ranged in age from 20 to 34 yr. All had normal vision and were not receiving drugs or medication at the time of testing.

Apparatus. Monocular visual stimuli were generated by a Maxwellian-view optical system. The light beam was supplied by a 150-W tungsten–halogen lamp powered by a regulated supply to produce a continuous and highly reliable light source. Infra-red rays were removed from the light beam by a glass, heat-absorbing filter. Unpatterned white light flashes were produced by an electronic shutter positioned in the path of the light beam. Flashes were presented at the rate of 1/sec with a 50-msec duration and a 1-msec rise–fall time. The optical system focused a 2-mm diameter image of the filament in the plane of the subject's pupil such that the beam passed unhindered within the area of the constricted pupil. Therefore, changes in pupillary diameter could not affect the amount of retinal illuminance. The beam subtended a 22° visual angle on the retina. The light beam was reflected off a Macbeth test plate having a reflectance of 0.8 and measured using a Macbeth Illuminometer. This value in foot-candles (8.7) was converted to millilamberts (mL) and the retinal illuminance in trolands (tr) was computed using the formula: $\text{tr} = (10^7)(\text{mL})(D^2)/r$, where D^2 is distance from Maxwellian focus to test plate in meters and r is reflectance of the test plate. The maximum available retinal illuminance was determined to be 5.9×10^5 tr. Retinal illuminance was adjusted in 1.0 log unit steps using neutral density filters in conjunction with a balanced pair of neutral density optical wedges. A digital photometer was used to calibrate the neutral density optical wedges and filters. The shutter, lamp, and filters were secured on an optical bench located outside of a double-walled IAC chamber. The light beam projected through the glass windows of the chamber to prevent any possibility of acoustic stimuli reaching the subject.

PROCEDURES

Recording electrodes were located on O_z and C_z with the indifferent and ground electrodes placed on the earlobes. Electrodes impedance was maintained below 2 Kohms. Following electrode application, subjects were taken to an electrically shielded, sound-attenuated IAC chamber where they were positioned directly in line with the light beam. The height of the chair and the chin and forehead rests were adjusted to bring the subject to the appropriate viewing position, such that the light beam passed unhindered through the pupil of the right eye. The left eye was covered with an opaque patch. Subjects were instructed to relax, and maintain fixation on the center of the light flash with the aid of a fixation point. Subjects were shown how improper alignment with the light

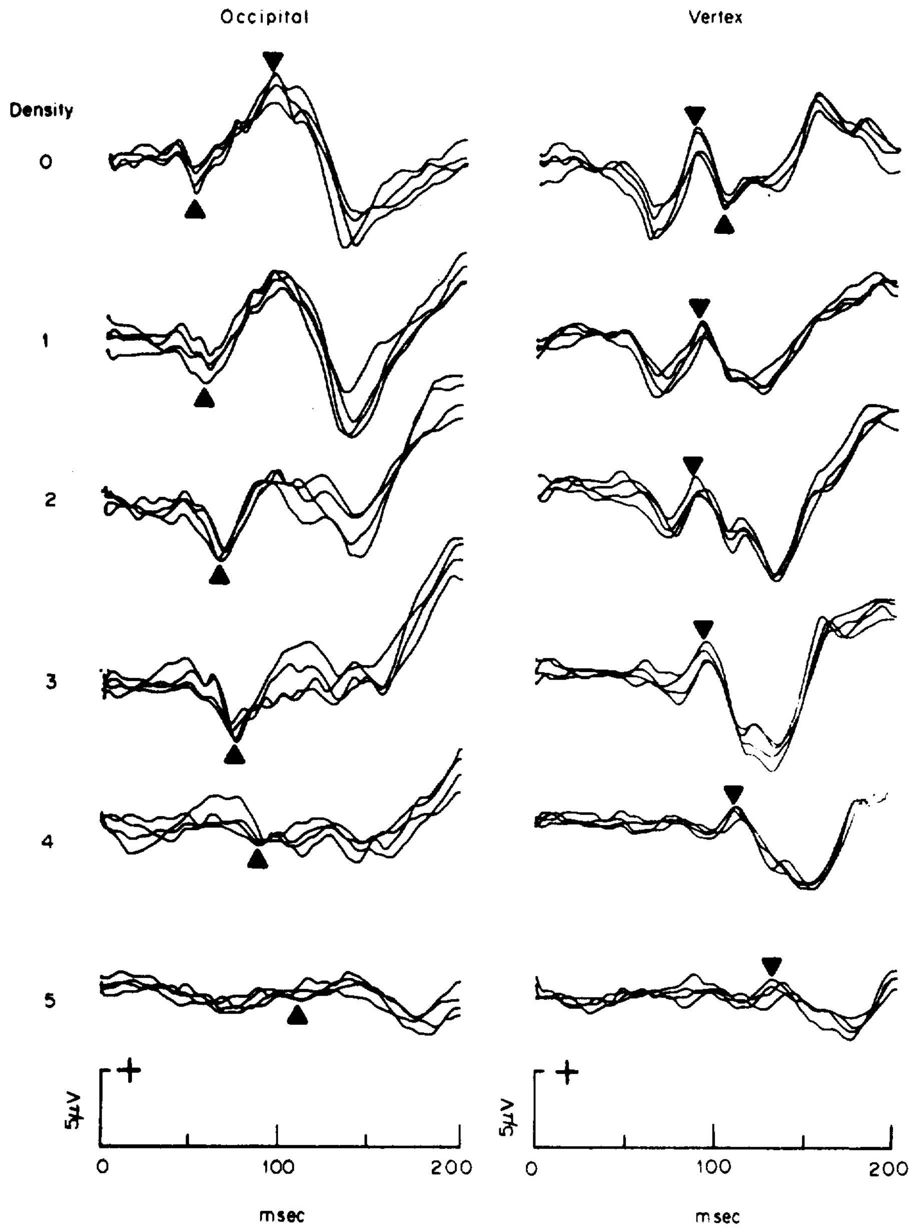

Fig. 1. Average VEPs recorded from one subject on four separate recording sessions. Density refers to neutral density filters which attenuate the light flashes in one log steps from very bright referred to as 0 density to very dim (5 density). Each average consists of 200 artefact-free sweeps recorded simultaneously from O_z–ear and C_z–ear. Upward deflection indicates the active electrode was positive with respect to the ear electrode. The darkened triangles indicate the N_{70}–P_{95} occipital component and the P_{95}–N_{145} or P_1–N_1 vertex component typically measured in human augmenting–reducing studies.

beam produced distortions in the visual image and were shown how to maintain proper alignment and fixation. This alignment procedure continued until they were comfortable and could maintain fixation. The room lights were lowered producing an ambient illumination of 34 ft L and the subjects adapted for 5 min to this reduced level of illumination. Subjects received five flash intensities in steps of 1.0 log unit in a counterbalanced ascending–descending order, with 100 light flashes presented at each intensity. Subjects counted the number of light flashes which occurred and reported this number at the end of each trial. The actual number of stimuli presented varied on each trial due to the number of artefacts rejected by the computer. Subjects initiated each trial when in proper alignment and ready to concentrate, and were given ample rest breaks throughout the experiment. Electrical activity from C_z and O_z was amplified 10,000 times with a bandpass of 1–100 Hz and recorded along with the trigger pulse on FM tape. The VEPs were computer averaged until 100 artefact-free sweeps were collected and written out on an X–Y plotter. The averager utilized 1024 data points and a 300-msec sweep. The artefact reject mode rejected sweeps in excess of 90% of full-scale voltage (50 μV) to eliminate data contaminated with voltage transients associated with eye blinks or other muscular activity. Although the computer did not have the capability of counting artefacts, observations made during data collection indicated artefacts were relatively homogeneously distributed across intensity. Prior to each data collection session, a 10-μV calibration pulse was averaged and plotted. Latency and amplitude measurements were obtained directly from the computer's oscilloscope screen by independently positioning two cursors along the VEP. Different components were measured from the O_z and C_z VEPs as shown in Fig. 1. Latency functions were examined to insure that the appropriate component was measured at all intensities. Linear regression analyses were then computed for latency and amplitude functions at O_z and C_z for the six intensities spanning a 5 log unit range. The term 'density' in the figure captions refers to neutral density filters which attenuated the light beam from 0 neutral density (very bright) to 5 neutral density (very dim).

RESULTS

The VEP components examined in this study were the occipital N_{70}–P_{95} component (Tepas *et al.*, 1974) and the vertex component (P_{95}–N_{145} or P_1–N_1) typically measured in human A/R studies. Components were identified following comparison of the latency and polarity with previously reported VEP topographic analysis (Allison, Matsumiya, Goff and Goff, 1977). Care was taken to insure that the same component was measured across intensities both within and between subjects. The latency of the O_z component (N_{70}–P_{95}) clearly and consistently decreased and its peak-to-peak amplitude increased as retinal illuminance increased (Fig. 1). A similar, although less pronounced, trend was observed at the vertex where multiple overlapping components in the same latency domain sometimes made component identification difficult. In these cases, examination of VEPs produced by light intensities bracketing that of the suspect potential was necessary in order to detect and measure the appropriate component. The O_z component was seldom difficult to detect or measure. Figure 1 also demonstrates the striking and consistent changes in VEP morphology observed with alterations in retinal illuminance.

For latency measurements, all 10 subjects had negative correlations with light intensity and negative slopes at both O_z and C_z recording sites (Table 1). Pooled latency for all subjects was highly correlated with light intensity and provided slopes of -10.6 msec/log unit and -8.4 msec/log unit at O_z and C_z, respectively. As expected for latency, the main effects for stimulus intensity [$F(5,45) = 146.3$, $P < 0.001$] and recording area [$F(1,9) = 30.2$, $P < 0.001$] were significant. There was also a significant recording area × intensity interaction [$F(5,45) = 3.1$] indicating that O_z had a greater latency slope than C_z. Examination of the latency slopes indicated they were not significantly correlated ($r = 0.01$).

For amplitude measurements, all subjects had positive correlations with light intensity and positive slopes recorded at O_z and C_z (Table 1). Pooled amplitude data provided positive correlations with light intensities of 0.96 and 0.95 and slopes of 1.3 μV/log unit and 0.7 μV/log unit for O_z and C_z, respectively. The main effects for recording area [$F(1,9) = 6.1$, $P < 0.05$] and intensity [$F(5,45) = 39.6$, $P < 0.001$] were significant. The O_z component was 30% larger (5.7 μV vs 4.0 μV) and both the O_z and C_z components increased in amplitude as retinal illuminance

Table 1. VEP slope and correlation with light intensity

	Latency				Amplitude			
	Occipital		Vertex		Occipital		Vertex	
Subject	*r*	Slope*	*r*	Slope*	*r*	Slope†	*r*	Slope†
1	−0.85	−9.3	−0.86	−9.2	0.90	1.7	0.92	0.8
2	−0.97	−10.3	−0.89	−7.4	0.68	0.6	0.74	0.3
3	−0.96	−11.6	−0.97	−4.5	0.83	1.1	0.63	0.4
4	−0.94	−11.9	−0.89	−7.5	0.98	1.6	0.91	0.3
5	−0.86	−11.2	−0.93	−10.0	0.94	1.1	0.89	0.4
6	−0.90	−13.8	−0.83	−8.9	0.95	1.3	0.84	0.9
7	−0.89	−11.9	−0.94	−10.3	0.96	1.0	0.88	1.7
8	−0.92	−10.6	−0.93	−10.6	0.94	1.1	0.47	0.4
9	−0.84	−9.9	−0.91	−4.3	0.72	1.0	0.60	0.5
10	−0.95	−5.6	−0.84	−8.8	0.95	2.3	0.94	1.0
Mean	−0.92	−10.6	−0.94	−8.4	0.96	1.3	0.95	0.7

*msec/log unit.
†μV/log unit.

increased. However, there was also a significant recording area × intensity interaction [$F(5,45) = 5.6$, $P < 0.001$] with the O_z slope greater by approximately a factor of two. Nine subjects had steeper O_z slopes, and in eight cases the difference was by a factor of two or greater. As with the latency data, the amplitude slopes for O_z and C_z were not correlated ($r = 0.23$).

Two subjects repeated the same evoked potential procedures on four additional recording sessions to determine the stability of the VEP slope calculations. Data from one subject are shown in Fig. 1. Correlation and slope calculations for latencies were all negative and quite similar at O_z and C_z (Table 2). Conversely, the amplitude slopes were more variable, with subject 4 having a negative or reducing C_z slope. As in the main study, the O_z amplitude slopes were always greater than C_z slopes. A striking example of the dissociation of the effects of light intensity at the two recording sites can be seen on session 4, subject 4 (Table 2), where 86% of O_z amplitude variability was accounted for by light intensity; whereas, only 0.5% of the variability could be similarly accounted for at C_z. Since the two potentials were averaged simultaneously and the O_z data were clearly related to retinal illuminance, the negative C_z slope cannot be due to inadequate stimulus control or to selective avoidance of particular light intensities. These sources of variance would affect the O_z component also.

CONCLUSIONS

The Maxwellian-view optical system offers distinct advantages over a free viewing situation. Since the light beam is focused at the plane of the pupil and falls entirely within the aperture of the completely constricted pupil, pupillary responses cannot affect the retinal illuminance. In addition, unlike photostimulators in which the light discharge is critically dependent on momentary voltage which can vary from flash to flash, this system depends on a regulated power source which maintains the lamp's output at a constant level. An electronic shutter positioned in the path of

Table 2. VEP slope variability

		Latency				Amplitude			
		Occipital		Vertex		Occipital		Vertex	
Subject	Session	*r*	Slope*	*r*	Slope*	*r*	Slope†	*r*	Slope†
	1	−0.97	−10.7	−0.88	−8.4	0.79	1.6	0.23	0.3
4	2	−0.97	−12.6	−0.90	−8.5	0.90	1.4	0.23	0.1
	3	−0.97	−12.9	−0.87	−10.7	0.97	1.8	0.29	0.4
	4	−0.99	−12.1	−0.88	−8.5	0.93	2.0	−0.07	−0.1
	$\bar{X}$	−0.98	−12.1	−0.88	−9.0	0.90	1.7	0.17	0.2
	SD	0.01	1.0	0.01	1.1	0.08	0.2	0.16	0.2
	1	−0.90	−8.1	−0.93	−9.6	0.84	0.8	0.32	0.3
1	2	−0.93	−8.5	−0.91	−11.3	0.92	1.3	0.13	0.2
	3	−0.92	−7.7	−0.92	−10.0	0.69	0.9	0.17	0.1
	4	−0.89	−7.9	−0.86	−10.8	0.73	0.8	0.44	0.4
	$\bar{X}$	−0.91	−8.0	−0.91	−10.4	0.80	1.0	0.27	0.2
	SD	0.02	0.4	0.03	0.8	0.10	0.2	0.14	0.1

*msec/log unit.
†μV/log unit.

the light beam produces a flash of constant intensity. Intensity can be calibrated and adjusted in precise amounts with neutral density filters and wedges. Finally, since the optical devices are external to the recording chamber, there are no acoustic artefacts.

Using these stimulus and recording procedures, the VEP was found to vary in a highly systematic fashion with changes in retinal illuminance. Pooled data from all subjects indicated that a linear regression fit to these data accounted for over 84% of the variance for latency and over 90% for amplitude. Examination of the individual slopes indicated that although the C_z amplitude slopes were lower than O_z slopes, the standard deviations were almost identical: 0.48 at O_z and 0.44 at C_z. Amplitude variability at each intensity for the two recording areas were also similar with values ranging from 1.3 to 3.2 at O_z and 1.1 to 2.4 at C_z, with O_z standard deviation greater than that of C_z at each intensity.

Although only positive vertex slopes were observed, this does not rule out VEP reducing. The sample may not have included any reducers or, more likely, the very large intensity range precluded finding negative slopes. In fact, three subjects were reducers for the highest intensities, and Table 2 contains a negative slope. In addition, Kress (1976) reported curvilinear vertex slopes using a Maxwellian optical system and a smaller intensity range. Although the control procedures used in this study preclude most artefactual sources from affecting the slope, other factors such as attention (Schechter and Buchsbaum, 1973) and arousal (Birchall and Claridge, 1979) can and do affect the slope of the amplitude–intensity function. As pointed out by Birchall and Claridge, although the A/R phenomenon is partially state dependent, subjects maintain their relative rankings across repeated A/R tests.

Results from the first study support the lawful relationship between stimulus intensity and neural response and therefore provide a suitable base for examining personality correlates of C_z amplitude slope. Augmenters are sensation seekers as measured by Zuckerman's Sensation Seeking Scale (Buchsbaum, 1971; Como, 1984; Coursey, Buchsbaum and Frankel, 1975; von Knorring, 1981). Zuckerman (1984; Zuckerman *et al.*, 1974) has reported that the correlation with A/R is often the strongest with the disinhibition scale, which measures a hedonistic pursuit of extraverted activities such as social drinking, parties, sex and gambling (Zuckerman *et al.*, 1974). Animal augmenters are explorative, active and responsive to novel and exciting stimuli in a manner suggestive of sensation seeking (Hall, Rappaport, Hopkins, Griffin and Silverman, 1970; Lukas and Siegel, 1977a). Another measure of A/R was developed by Vando (1974), based on Petrie's original formulation of stimulus intensity modulation. Therefore, the second experiment examined the relationship between sensation seeking and the VEP slopes under the conditions of precise stimulus control developed in the first experiment.

EXPERIMENT 2

Subjects. Twenty-two college students were paid to serve as subjects. None of these subjects participated in the first study. There were 9 males and 13 females ranging in age from 19 to 36 yr. All subjects had normal vision and were free from medication at the time of testing.

Method

The Maxwellian-view apparatus and stimulus conditions were identical to the first study except that a bite board covered with dental impression wax was used to align and stabilize subjects. In addition, the dimmest flash was eliminated since VEP components at this intensity were sometimes difficult to detect and measure. Also, a smaller range of bright flashes would enhance the probability of observing reducing slopes. Following completion of the evoked potential procedure, subjects completed Form V of Zuckerman's Sensation Seeking Scale and Vando R–A Scale. The Sensation Seeking Scale (SSS) consists of 10 items for each of four factors; thrill and adventure seeking (TAS), which measures interest in physical risk-taking activities such as parachuting; experience seeking (ES) reflects interest in music, art, drug use, and a spontaneous lifestyle; disinhibition (DIS) measures a hedonistic, extraverted lifestyle including drinking, parties, sex and gambling; boredom susceptibility (BS) indicates an aversion to routine activities or boring people. A total score is based on all 40 items.

The Vando R–A scale was developed to measure Petrie's conceptualization of stimulus intensity modulation. Since reducers are thought to attenuate sensory experiences (Petrie, 1967), they should be relatively stimulus deprived and therefore should seek out and prefer high levels of stimulation. Reducers according to Vando (1974) are sensation seekers and in fact the Vando R–A scale significantly correlates with the SSS (Goldman, Kohn and Hunt, 1983; Kohn and Coulas, 1985). Reducers on the R–A scale were more pain tolerant, extraverted and smoked more than augmenters. In addition, reducers were less hypochondriacal and slept less. Both the VEP augmenter and a Vando reducer are thought to be sensation seekers. These conflicting results may depend on whether Buchsbaum's EP procedure or Vando's personality test is used to select groups. Comparing subjects on the SSS, R–A scale and the VEP A/R procedure might provide some resolution of this conflict.

RESULTS

Of the 22 subjects who participated in this study, 16 had clear VEPs at both O_z and C_z. One subject's data were lost due to equipment malfunctions and three subjects were removed from the analyses since their VEPs were distorted and consistent VEP components could not be found at O_z or C_z. Two subjects had measurable VEPs at one recording area and their data are also included in the correlation analyses. The remaining 16 subjects were divided by a median split into two groups of eight based on their DIS scores (Zuckerman *et al.*, 1974). Scores from the high DIS group ranged from 5 to 9 ($\bar{X} = 6.8$) while the low DIS group ranged from 0 to 4 ($\bar{X} = 2.8$). Tests for equal variances and correlations for the VEP amplitude data indicated that a multivariate analysis was appropriate.

As in Experiment 1, for amplitude data the main effects for cortical area and intensity were highly significant ($P < 0.001$). The O_z component was 93% larger than C_z (7.85 μV vs 4.07 μV) and both components augmented as intensity increased. However, the slopes for O_z and C_z were significantly different as indicated by an area × intensity interaction ($F = 5.76$, $P < 0.01$) with the O_z slope measuring 1.07 μV/log unit and C_z slope less than a third of that, 0.32 μV/log unit. The most interesting result from this analysis is shown in Fig. 2, which represents the significant three-way interaction of disinhibition × recording area × intensity ($F = 3.48$, $P < 0.05$). As can be seen, both high and low disinhibitors had very similar and augmenting O_z slopes (1.02 and 1.13 μV/log unit). In contrast, whereas the high disinhibitors also had augmenting C_z slopes (0.60 μV/log unit), the low disinhibitors achieved the highest VEP amplitude at the next to lowest intensity producing a virtually flat slope (0.04 μV/log unit). Since the two areas were averaged simultaneously and the O_z data clearly augmented, then the reducing C_z pattern cannot be due to inadequate stimulus control or selective avoidance of the brighter flashes.

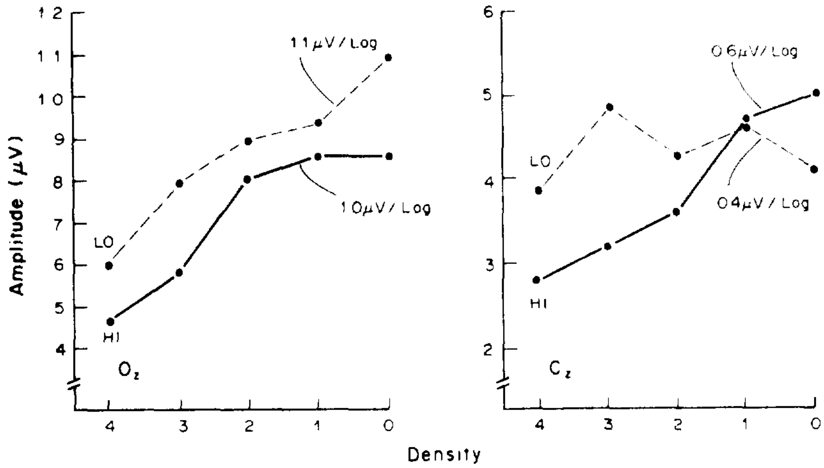

Fig. 2. Significant disinhibition × recording area × intensity interaction. The VEP amplitudes for low and high disinhibitors on Zuckerman's Sensation Seeking Scale are plotted vs flash intensity (referred to as density of the neutral density filters) for the occiput and vertex recording areas. The linear slopes are also presented for each set of data.

Table 3. Correlation of personality scores and amplitude slopes

	Amplitude slopes			
Personality	O_z	O_zT	C_z	C_zT
Vando	0.06	0.04	0.38	0.40
SSS total	0.09	−0.01	0.40	0.50*
Dis	−0.07	−0.05	0.26	0.40

T—transformed data (maximum voltage = 1.0 μV).
*$P < 0.05$ ($df = 16$, two-tailed).

For latency measurements, there were no significant interactions with intensity or disinhibition. As was found in the first experiment, the main effect for intensity was significant ($P < 0.001$). The latency slopes for both O_z and C_z were negative (−7.0 and −5.6 msec/log unit), indicating that peak latency decreased as intensity increased.

As shown in Table 3, the occipital amplitude slopes did not correlate with either the SSS or Vando scales. Examination of the relationship between VEP amplitude and slope indicated that subjects with larger evoked potentials tended to have higher slopes. Correlating the maximum amplitude and slope from the 26 subjects participating in both studies indicated a highly significant relationship at both O_z ($r = 0.76$, $P < 0.01$) and C_z ($r = 0.64$, $P < 0.01$). Therefore, data for O_z and C_z were transformed separately such that the maximum voltage was set at 1.0 μV and all other values were scaled appropriately. Following this transformation, the correlations between maximum amplitude and slope were essentially zero for both recording areas. However, the occipital slopes were not correlated with the personality measures and tended to hover around zero. When the O_z data were remeasured to include the component nearest in latency to the vertex P_1–N_1, the occipital amplitude slope still did not correlate with sensation seeking ($r = 0.33$). A different and consistent picture emerged at the vertex: the correlations were all positive and the SSS total score was significantly correlated with the slope. In other words, the vertex augmenter is a sensation seeker. Both the Vando R–A scale and the DIS scale were positively but nonsignificantly correlated with the vertex slope. Since the DIS scale was not significantly correlated with the amplitude slopes, the MANOVA was repeated using the SSS total score. Subjects were divided at the 50th percentile based of norms for college students (Zuckerman, 1979). Scores for the high sensation seeking group ranged from 20 to 32 with a mean of 24.8 while the low sensation seeking group ranged from 14 to 19 ($\bar{X} = 17.4$). As with the MANOVA for DIS, there was a significant SSS × recording area × intensity interaction ($F = 5.04$, $P < 0.01$). Both groups had augmenting occipital slopes (1.28 and 0.98 μV/log unit). At the vertex, the high sensation seekers were augmenters (0.49 μV/log unit) while the low sensation seekers produced the highest VEP amplitude to the next to lowest intensity producing a virtually flat slope (0.07 μV/log unit).

Sex differences. Buchsbaum (1976) reported finding sex differences in A/R, with women tending to augment more. To test for sex differences, data from both studies were combined yielding 12 males and 14 females. Men and women had virtually identical O_z slopes, 0.97 vs 1.08 μV/log unit. Although males had higher C_z slopes (0.60) than females (0.30), the difference was not significant. There were only six reducers, one male and five females. Examination of the VEP at each intensity at O_z and C_z indicated that men and women did not differ except for the middle intensity where women had a larger vertex VEP ($t = 2.09$, $P < 0.05$). Examination of the transformed amplitude data also indicated there were no significant slope differences for men and women.

DISCUSSION

These results indicate that vertex A/R occurs even under the most stringent stimulus and recording procedures. The linear and positive occipital slopes observed in both studies provide strong evidence that the appropriate degree of stimulus control was achieved. Consequently, considerable confidence can be placed on the vertex A/R phenomenon and its relationship with personality. It is also important to note that the vertex area is the appropriate recording locus for A/R in humans (Buchsbaum, 1976). In addition, several lines of evidence suggest that vertex and occipital VEPs provide very different insights concerning cortical functioning. Anatomically, the O_z electrode lies over the occipital pole and the vertex over pre-central cortex (Jasper, 1958). The

VEP waveforms are not similar in morphology (e.g. Fig. 1) and in fact, P_1 and N_1 occur at an earlier latency at C_z (Connolly and Gruzelier, 1982; Van Voorhis and Hillyard, 1977), suggesting these components arise from separate neural generators. In addition, decreasing the interstimulus interval from 6 to 0.5 sec clearly diminishes the vertex but not the occipital VEP (Lehtonen, 1973) and the two areas also have different components responsive to the effects of selective attention (Van Voorhis and Hillyard, 1977). The vertex potential is often considered nonspecific since its waveform is similar for auditory, visual, or somesthetic stimulation. Also, various intermodal effects on the vertex potential suggest that the neural generators are the same for different modalities (Davis, Osterhammel, Wier and Gjerdingen, 1972). However, C_z also contains activity from the primary sensory areas which may spatially and temporally overlap (Goff, Allison and Vaughan, 1978). The occipital potentials arise primarily from primary cortex with little contributions from anterior cortical regions (Vaughan, 1966); whereas, the vertex components arise from both primary sensory areas as well as other cortical and/or subcortical regions.

Results from the personality correlates for the two recording areas also support the conclusion that O_z is primarily involved with processing specific features of visual stimuli including intensity; whereas, C_z is related more to nonsensory factors such as attention or arousal (see also Kress, 1976). The occipital amplitude slope is linearly and positively related to flash intensity but is not correlated with any of the personality measures. In contrast, the vertex amplitude slope is significantly correlated with sensation seeking and positively correlated with scores on Vando's R–A scale. The Vando R–A scale is clearly based on a sensation-seeking motive (Vando, 1969). The VEP augmenter is a sensation seeker whether measured by Zuckerman's SSS (Buchsbaum, 1971; Como, 1984; Von Knorring, 1981; Zuckerman *et al.*, 1974) or Vando's R–A scale. The tendency for an EP augmenter and a Vando reducer to be a sensation seeker has recently been confirmed in the auditory modality (Lukas and Mullins, 1985; Mullins and Lukas, 1984).

According to Petrie, reducers are relatively stimulus deprived and therefore should be sensation seekers. Augmenters amplify sensory experience; consequently, they are sensitive to pain and tolerate confinement and isolation better than reducers. Clearly, Petrie's conceptualization of an augmenter does not fit a sensation seeker. In addition, Haier, Robinson, Braden and Williams (1984) recently reported that the VEP reducer is a sensation seeker and pain tolerant in accord with Petrie's original formulation of augmenting–reducing. The stimulus intensities used to select evoked potential augmenters and reducers is thought to play a key role in the resolution of this conflict (Claridge *et al.*, 1985; Robinson, Haier, Braden and Krengel, 1984). In fact, there may be two different A/R paradigms: one using moderate intensities (Buchsbaum, 1976; Haier *et al.*, 1984), which relates directly to Petrie's formulations of A/R and measures individual differences in CNS sensitivity; and the other using higher intensities (Lukas and Siegel, 1977a; Zuckerman *et al.*, 1974), which are sufficiently intense to activate inhibitory processes in certain subjects. The augmenter to moderate intensities because of their enhanced sensitivity may become a reducer at higher intensities (Claridge *et al.*, 1985; Petrie, 1967). Several lines of data tend to support this contention. Petrie, Holland and Wolk (1963) reported that KFA augmenters can become reducers when overstimulated, and that the greater the augmentation, the more pronounced the 'defensive reduction'. In a similar vein, Barnes (1976) described two types of reducers: trait reducers are relatively insensitive to begin with; whereas, state reducers, such as schizophrenics, develop protective inhibition as a result of overstimulation and actually function as augmenters at lower stimulation levels. Interestingly, male VEP reducers were more sensitive based on their sensory thresholds (Silverman, Buchsbaum and Henkin, 1969), yet when the flash intensity was lowered by one log unit, these subjects now had larger VEPs and a slightly steeper slope (Buchsbaum and Pfefferbaum, 1971).

The role of stimulus intensity in defining A/R is clearly problematic since each laboratory uses different intensities, durations and stimulation procedures and few provide sufficient details to determine the effective intensity. Unfortunately, the artefactual sources of slope variability discussed by Tepas can also interact with stimulus intensity to further complicate the picture. In the present study, the slope calculations were derived from a 4 log intensity range much broader than either the Grass photostimulator (1.2 log) or Buchsbaum's apparatus (1.9 log) and certainly include both medium and high intensities. Although this study was not designed to examine the issue of intensity range, the arguments put forth by Robinson and Claridge warrant *post hoc* analyses to provide some preliminary evidence. Consequently, the data were divided into a medium intensity range (4, 3, 2 N.D. filters) and a high range (2, 1, 0 N.D. filters). Since there were only five intensities and a slope based on two intensities was not appropriate, the No. 2 N.D. filter was included in both ranges. The vertex slopes from the medium and high range both correlated significantly with the slope for the entire intensity range ($r = 0.53$, $P < 0.05$) but were negatively and nonsignificantly correlated with each other ($r = -0.35$). A median split of the slopes for the medium range produced eight augmenters (slope = 1.0 μV/log unit; range of 0.51 to 1.5 μV/log unit) and eight reducers (slope = -0.37 μV/log unit; range of -0.92 to 0.18 μV/log unit). If augmenters are more sensitive, then they should be pushed into protective inhibition and reduce at higher intensities (Claridge *et al.*, 1985). The augmenters did in fact reduce at the high range (slope = -0.10; range of -0.75 to 0.85), with five subjects now having a negative vertex slope. In addition, augmenters at the medium range had larger $P_1 - N_1$ amplitudes to all intensities which were statistically significant at neutral density 2 ($t = 3.85$, $P < 0.01$) and 1 ($t = 2.34$, $P < 0.05$). These analyses do tend to support the contention that augmenters to moderate intensities tend to reduce at higher intensities. The question as to the role of intensity on the relationship of A/R with sensation seeking is more germane to the present discussion. Therefore, when the analysis was repeated using the SSS total scores, both high and low sensation seekers were augmenters at the medium range (high SSS = 0.40 μV/log unit and low SSS = 0.14 μV/log unit). At the higher intensities, high sensation seekers were augmenters (slope = 0.57 μV/log unit); whereas, the low sensation seekers were reducers (slope = -0.23 μV/log unit). Further, slopes for the medium intensity did not significantly correlate with the SSS total ($r = 0.10$), Dis ($r = -0.03$), or Vando R–A scale ($r = 0.02$); whereas, slopes for the high range were correlated with the SSS total ($r = 0.45$, $P < 0.05$) and positively but not significantly correlated with DIS ($r = 0.39$) and the Vando R–A scale ($r = 0.35$). These analyses further support the finding that VEP augmenters are sensation seekers and indicate that the relationship is seen primarily in response to high intensity light flashes.* Very similar findings were reported for animal A/R (Lukas and Siegel, 1977a), where again it was the slopes to the high rather than moderate intensity flashes that correlated with a constellation of behaviors considered to be indicative of sensation-seeking trait (Zuckerman *et al.*, 1980). Apparently, how cortical neurons respond to intense afferent stimulation relates to how that individual will respond behaviorally. The VEP reducer to intense visual stimuli does not cope well with aversive or stressful stimulation (Lukas and Siegel, 1977a,b) or seek out novel and exciting experiences (Zuckerman *et al.*, 1974), nor do they perform well under high mental workloads (Lukas and Mullins, 1985). Augmenting–reducing appears to offer an entrée into the nervous system with implications for personality and a wide range of behaviors.

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